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Plant diversity on skid trails in oak high forests: A matter of disturbance, micro-environmental conditions or forest age?

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ABSTRACT

Increasingly mechanized timber harvesting and the repeated use of skid trail networks may affect ground vegetation differently at subsequent stages in the forest rotation. At a fine scale, no studies have yet compared the influence of micro-environmental factors and the effects of skid trail disturbance on ground flora diversity. We investigated understory diversity patterns on skid trails in 30-, 50- and 63-year-old oak forests in the northern half of France. Subplots were placed on skid trail center, wheel track, skid trail edge plus an off-trail control. At each subplot, we measured soil moisture, soil compaction (penetration resistance and bulk density) and photosynthetic active radiation and recorded the abundance of all vascular plants. The richness and abundance of ground flora were calculated based on the classification of their life form, seed bank persistence, light preference and moisture requirements. For each ecological group, we found out its best diversity indicator from subplot location, micro-environmental factors (soil moisture and compaction, light) and stand attributes (stand type, basal area), then assessed the magnitude and negligibility of the effect of the best indicator. (1) Higher soil compaction compared to controls was detected on the tracks of skid trails in the 50- and 63-year-old stands. Neither soil moisture nor light varied with subplot location whatever the stand type. (2) The best diversity indicator that showed non-negligible effects included subplot location, and soil moisture or soil compaction. Compared to controls, skid trails in the 50- and 63-year-old stands were richer in tree and short-term seed bank species, while skid trails in the 30-year-old plots had no effect on ground flora. The abundance of tree and shade-tolerant species was also higher on skid trails. Soil moisture was positively correlated with the richness of low- and high-humidity species, shade-tolerant species and transient seed bank species as well as with the abundance of short-term seed bank species. Bulk density positively affected heliophilous species richness, while penetration resistance was positively related to shrub abundance. Skid trails and soil compaction in our research area had either no impact or a positive impact on ground flora diversity. Longer-term studies of skid trail effects are needed to validate these main findings.

1. Introduction

Successful forest management requires a thorough understanding of how forest ecosystems respond to disturbances. Disturbances, such as tree harvesting, are a primary factor influencing diversity and floristic composition in the forest (Roberts and Gilliam, 1995; Berger et al., 2004). During the last several decades, manual felling and logging for forest management have evolved towards mechanized harvesting. Mechanized logging and timber harvesting rely on permanent evenly-distributed skid trail systems (Jarret, 2004), which have the advantage of confining disturbances to relatively smaller areas (Akbarimehr and Jalilvand, 2013) while providing easy access to the forest interior (Avon et al., 2013). The micro-site environment on skid trails is likely to differ from that of the forest interior due to canopy opening, higher soil compaction, soil nutrient loss or increased soil moisture on skid trails compared to undisturbed habitat (Buckley et al., 2003; Zenner and Berger, 2008; Hattori et al., 2013). These environmental changes might explain the differences in ground flora that is observed between locations on and off skid trails (Swaine and Agyeman, 2008; Wolf et al., 2008; Avon et al., 2013). Canopy cover is one of the most important factors that control a site's microclimate (Metzger and

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Schultz, 1984). Opening the canopy along skid trails can influence plant growth and competition patterns, especially between shade-tolerant and -intolerant species (Horn, 1971; Planchais and Sinoquet, 1998). However, light level may not always remain high on skid trails years after logging or cutting operations. The time necessary for canopy closure together with the properties of the residual tree stands (age, height...) can greatly influence light availability on skid trails.

Soil compaction, a reduction in the volume of a given mass of soil (Gliński and Lipiec, 1990), is one of the major consequences of mechanized harvesting on skid trails (Ampoorter et al., 2010; Naghdi et al., 2010; Solgi and Najafi, 2014). Therefore, it is often used as an indicator of forest floor disturbance resulting from machine use on skid trails. Very few studies to date have directly related ground flora to soil compaction measured on skid trails. For instance, Buckley et al. (2003) measured soil compaction in their description of the growth conditions on skid trails, but did not directly link it to ground flora diversity in the statistical analyses. We found only two studies investigating the relationship between soil compaction on skid trails and ground flora, however, their results were not consistent. Roovers et al. (2004) demonstrated that the intensity of soil compaction was highly (negatively) correlated with species cover and composition. On the contrary, Heninger et al. (2002) found that reduced Douglas-fir tree seedling growth on skid trails was unrelated to percentage increases in soil bulk density. Therefore, the role of compaction on skid trails in ground flora diversity needed to be validated.

Soil moisture is an important fine-scale factor affecting plants that has been described in many studies (Beckage et al., 2000; Gray et al., 2012), but those dealing with skid trails did not find consistent results. For example, some studies demonstrated that soil moisture was higher on skid trails due to the removal of the canopy cover which reduced rainfall intercept and increased water intercept in the soil, while others found decreased water holding ability in wheel ruts after the first machine passes (Miller and Sirois, 1986; Buckley et al., 2003; Ezzati et al., 2012; Solgi and Najafi, 2014). Since the influence of canopy cover and machine use on soil moisture had not yet been jointly compared, we still need to study the soil moisture level on skid trials and its relation to canopy cover and soil disturbance.

Ground flora has the highest species diversity of all forest layers in temperate forests (Thomas et al., 1999). Because the diversity of ground flora is sensitive to a variety of factors such as overstory characteristics (Augusto et al., 2003; Nagaike et al., 2005; Barbier et al., 2008), soil properties (Brunet et al., 1996), and forest disturbances and management practices (Hammond and Miller, 1998; Wender et al., 1999), it is an important indicator of forest site quality and of the environmental impact of management (Pregitzer and Barnes, 1982; Gilliam, 2002). The presence of skid trails, associated with frequent machine entry and accompanying disturbances, favors the introduction of ruderal, non-forest, exotic or heliophilous species (Buckley et al., 2003; Zenner and Berger, 2008; Avon et al., 2013). Identifying species that successfully establish and grow on skid trails, or inversely, that decrease or disappear on skid trails, is an important step for forest managers (Buckley et al., 2003). Furthermore, for those species that are favored by skid trails, it is important to distinguish whether these species are native or non-native species, and whether they are exclusive species. An increase in non-native species may threaten the existence or growth of native species on skid trails, especially when non-native species disperse into the forest interior.

The relative importance of different environmental or historical filters (e.g. disturbance) for ground flora diversity may vary with forest stage or stand development (Burton et al., 2011). Stands of different ages and types within a forest frequently experience different management regimes, i.e. they are subjected to varying intensities of machinery use and different distribution patterns of skid trails (Zenner et al., 2007; Zenner and Berger, 2008). In addition, more mature forests managed with large machines need wider skid trails for wood extraction, potentially leading to the creation of deeper continuous ruts (Schack-Kirchner et al., 2007 and Picchio et al., 2012). Furthermore, trees at different ages may intercept different levels of light and water. Some studies have investigated the effect of skid trails on tree regeneration in different forest types (Liechty et al., 2002; Beaudet et al., 2014) but only limited research has compared the plant diversity patterns on skid trails in different forest types. Roovers et al. (2004) examined the effects of trampling on vegetation along skid trails in four vegetation types: two deciduous forest types, one grassland and one heathland, and showed that the increase in floristic dissimilarity from trail to undisturbed vegetation was higher in forests than in the grassland and the heathland, whereas no difference was detected between the two forest types.

Fine-scale studies of plant diversity patterns can provide insights into how historical and environmental filters interact across scales to influence vegetation locally (Leibold et al., 2004; Burton et al., 2011). No previous studies have ever compared the influence of micro-environmental factors with skid trail disturbance to detect their effects on ground flora diversity. In our study, we investigated fine-scale understory diversity patterns in three forest types of varying tree maturity containing skid trail systems. We aimed to find the dominant factors affecting ground flora diversity among subplot location, soil moisture, soil compaction, light, stand type and basal area. We used subplots on and off skid trails to indirectly represent habitat exposed to frequent and infrequent disturbances. In addition, within the skid trails, we used three different locations – the middle of the trail, the wheel track and the trail edge – to represent the within-trail disturbance gradient. Relationships between ecological or functional groupings of plant species and environmental gradients can provide evidence for environmental filtering, particularly when the traits suggest an advantage in the associated environment (McGill et al., 2006; Burton et al., 2011). The classification of ecological groups was based on the following four species traits (Table 1): life form, seed bank strategy, light and moisture requirements (data sources: Hodgson et al., 1995; Julve, 2007). Our research questions were as follows: (1) What is the relative importance of subplot location, soil moisture, soil compaction and light on ground flora diversity? (2) Does this importance vary with stand type? (3) Are the dominant factors different among ground flora ecological groups?

2. Material and methods

2.1. Study area

The Montargis forest (4090 ha, 48°01′ N, 2°48′ E, Loiret, northern half of France) is an ancient state forest managed by the French National Forestry Office (ONF) around 110 km south of Paris. Elevation ranges from 95 to 132 m a.s.l. Climate is oceanic with a respective mean annual rainfall and temperature of about 647 mm and 10.9 °C (Chevalier, 2003). Soil conditions are homogeneous, with plateau soils on a chalk substrate. There are small variations in soil texture (sandy to silt-sandy) and stone content (Chevalier, 2003). The dominant tree species are sessile oak (*Quercus petraea*), hornbeam (*Carpinus betulus*) and beech (*Fagus sylvatica*). The main management goal is to produce quality timber. Therefore, 70% of the area is managed as an oak even-aged high forest, where trees originate from seeds (Helms, 1998). Former standard-with-coppice (SWC) forest management with sessile oak as standards and hornbeam as coppice has been progressively replaced since 1857 by an even-aged high forest system dominated by oak. A high